ACEP
Alaska Center for Energy and Power

CCHRC
Cold Climate Housing Research Center

Ground Source Heat Pumps in Cold Climates

ALASKA ENERGY AUTHORITY

Denali Commission
10 Years Of Progress
1998-2008
Alaska

NREL
National Renewable Energy Laboratory

A REPORT FOR THE
DENALI COMMISSION

Framing the Report

- GSHP technology used extensively in the Lower 48 and internationally
- Limited cold climate applications
- Little is known about GSHP technology in AK
- GSHP technology could be very useful to AK, given heating costs in the state
- Many anecdotal stories of success… several high profile installations

A Collaborative Approach

- Report Collaborators:
  - Alaska Center for Energy and Power
  - Cold Climate Housing Research Center
  - Alaska Energy Authority
  - National Renewable Energy Laboratory
- Funded by the Denali Commission
- Ground Source Heat Pumps in Cold Climates

  "The Current State of the Alaskan Industry, a Review of the Literature, a Preliminary Economic Assessment and Recommendations for Research"

Report Overview

- 1st cut assessment
  - What are the challenges associated with cold climate applications
  - What research has been done, either in AK or other cold climates
  - What projects were/are installed in Alaska
  - What does the industry look like
  - Data analysis with any available project data
  - What are the preliminary economics of GSHP in AK?

Report Outline

Report Body

- Heat Pump Primer
- GSHPs in Cold Climates
  - Cold Climate Considerations for GSHP Applications
  - Current State of the Heat Pump Industry in Alaska
  - Preliminary Economic Analysis
- Major Findings
- Recommendations

Appendices

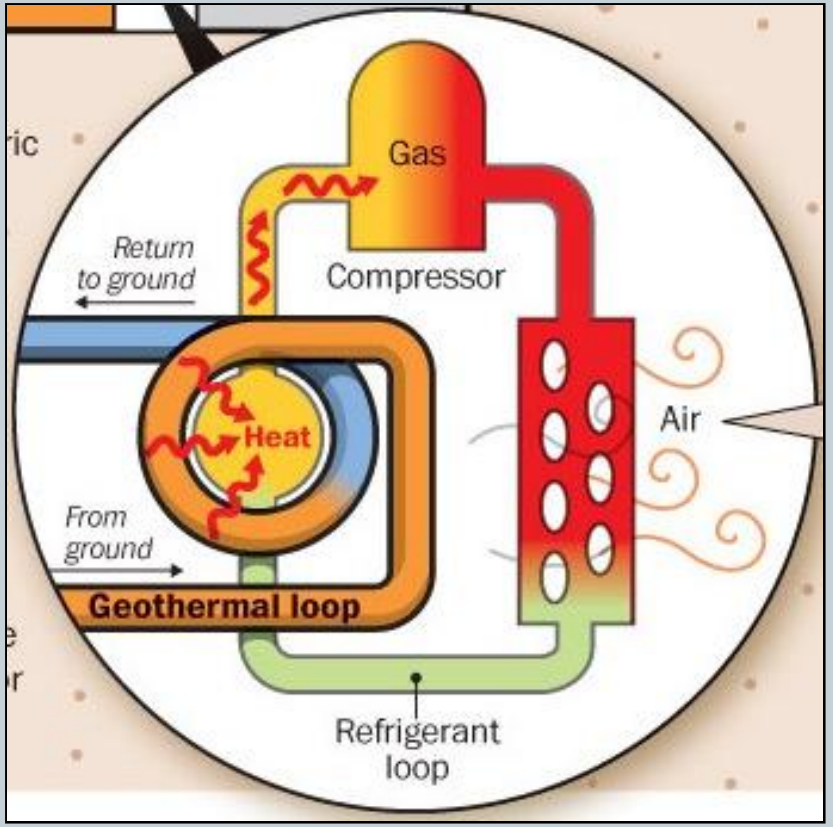
- Works Cited
- Inventory of Alaska GSHP Installations
- List of Interviewees
- Summaries of Selected Literature
- Annotated Bibliography

GSHP Technology Review

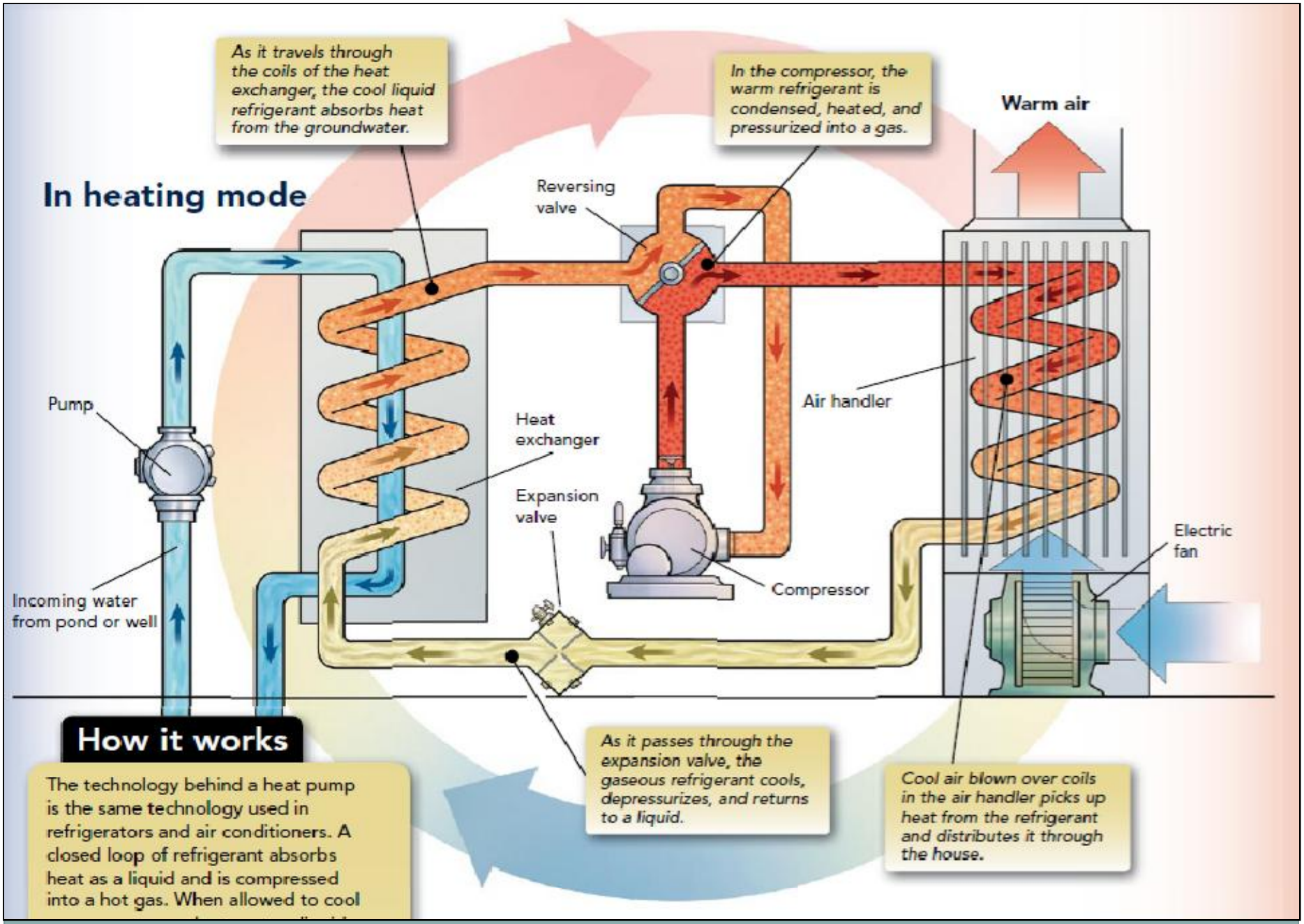
Technology Review – Heat Pump

Familiar technology, different application:

- Fridge or air conditioner
- Space heat by air or radiant hydronic
- Partial load for domestic hot water



Graphic source: Bonnie Berkowitz and Laura Stanton/The Washington Post

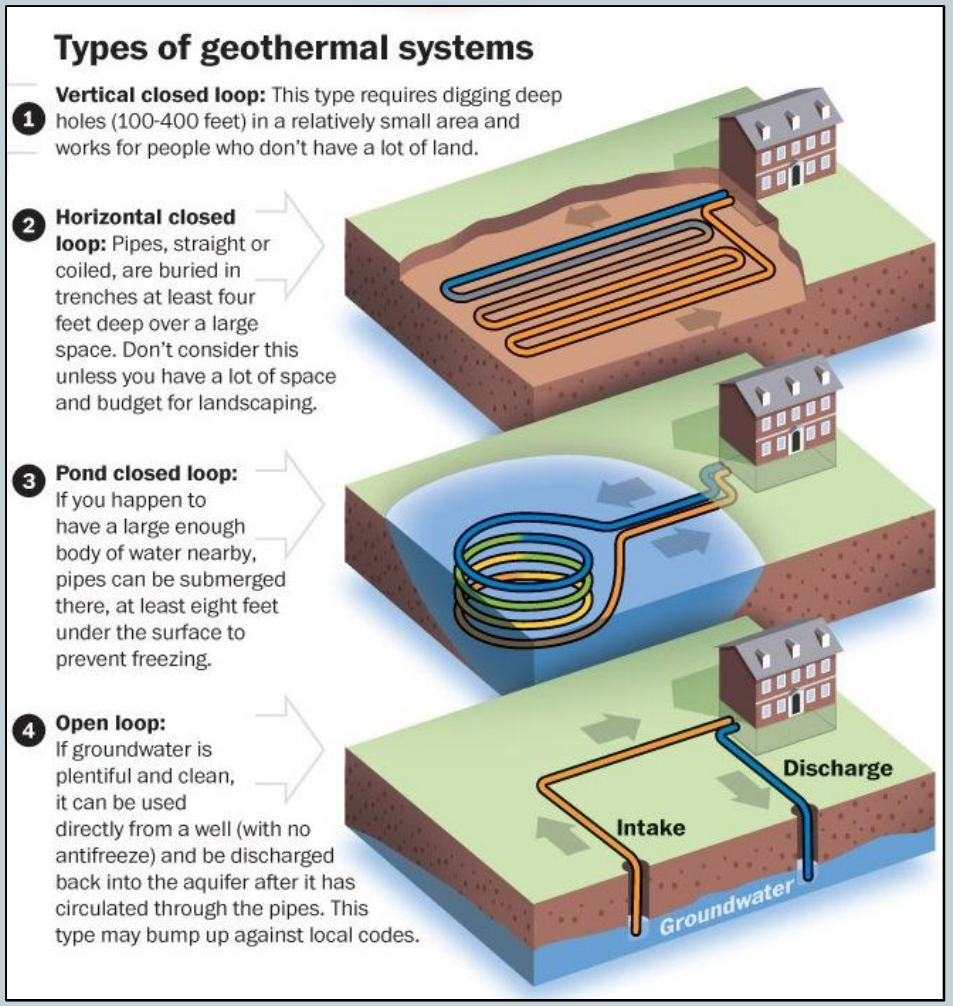


Graphic source: Gibson, S. /Fine Homebuilding

Technology Review – Ground Loop

Many options -

- Vertical wells
- Shallow trench
- Coil on lake bottom
- Open system

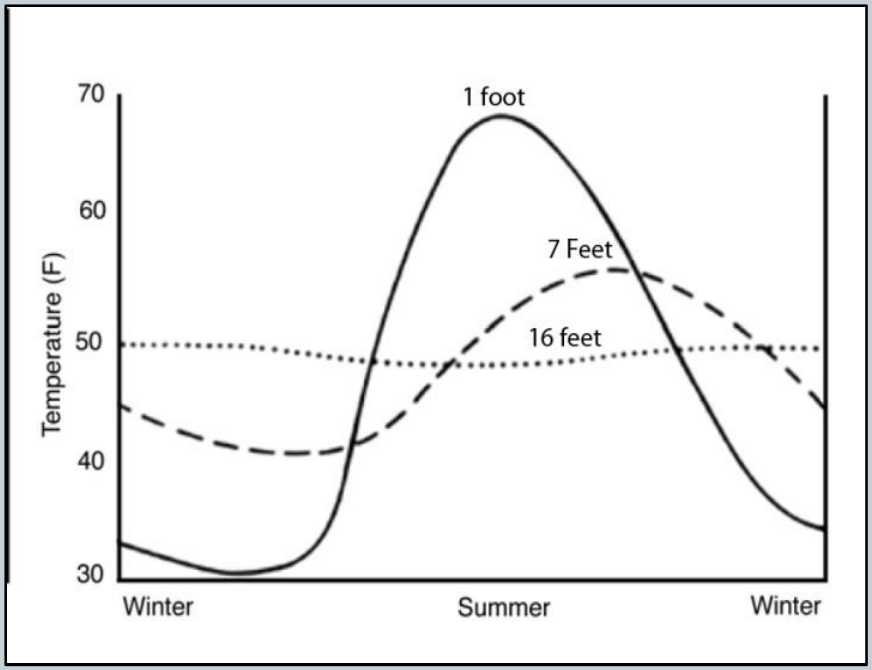


Graphic source: Bonnie Berkowitz and Laura Stanton/The Washington Post

Technology Review – Ground vs Air

Temperature variation –

- Ground temperature much less variable
- Deeper ground provides stability
- Seasonal lag between air and ground



Graphic source: Hanova & Dowlatabadi, 2007

Technology Review – Deployment

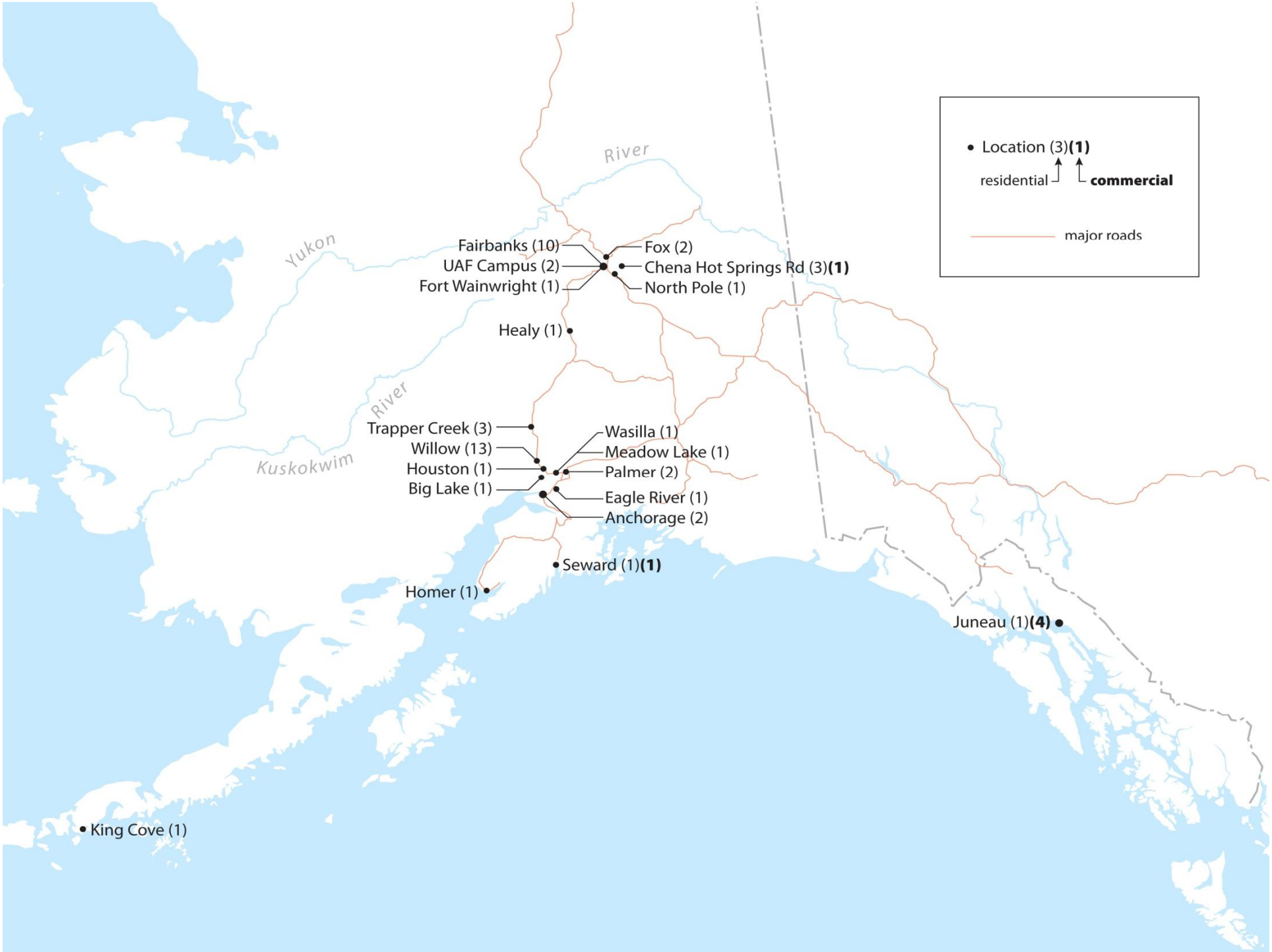
Familiar technology -

- 21,000 GSHP units at DoD facilities
- Majority are in Southeast and Midwest
- None are in very cold or subarctic regions

Alaska Industry and Installations

Alaska Installations

- Detailed database of all GSHP projects in the state
- COP values (where available), system type, location, installer, etc
- 49 residential systems
  - Willow, Fairbanks, Juneau, Homer, Palmer, Wasilla, Eagle River, Meadow Lakes, Houston, Seward, Fox, UAF, Fort Wainwright, King Cove, Big Lake, Trapper Creek, Anchorage,
- 6 commercial systems
  - Alaska SeaLife Center, Juneau Airport, Dimond Park Aquatic Center, AELP Office Building, Weller School, NOAA Auke Bay Laboratories


• Location (3)(1)
residential
commercial
major roads
River
Yukon
Fairbanks (10)
UAF Campus (2)
Fort Wainwright (1)
Fox (2)
Chena Hot Springs Rd (3)(1)
North Pole (1)
Healy (1)
River
Kuskokwim
Trapper Creek (3)
Willow (13)
Houston (1)
Big Lake (1)
Wasilla (1)
Meadow Lake (1)
Palmer (2)
Eagle River (1)
Anchorage (2)
Seward (1)(1)
Homer (1)
Juneau (1)(4)
King Cove (1)

Residential System Trends

- Majority are horizontal ground loop systems
- COP range from 2.2 – 3.98
- Interviewed owners had installed a GSHP for a variety of reasons
  - Each reported that long-term cost savings was a strong motivation
  - Many installed a GSHP in part because it is a partially renewable-energy technology
- All owners interviewed reported satisfaction with their systems.

Alaska Industry - Installers

- 13 installation business identified across the state
  - Fairbanks, Anchorage, Mat-Su Valley, Homer, Sitka, Juneau.
- High capital cost is a large barrier for potential residential and commercial consumers.
- Few engineering firms have/are involved in commercial systems. Limited experience with GSHPs as only 7 commercial systems have been installed across the state.

Alaska Industry - Drilling

- Drilling costs are high
  - Typically cannot compete with horizontal systems
- High cost due to a combination of ground conditions, limited competition, and available equipment
- In Juneau, rigs currently average around $20 per foot plus a mobilization fee
  - Drilling in the Seattle area can cost as little as $8 per foot
- Test holes/vertical boreholes for Juneau Airport were drilled by rigs from Seattle (cost/experience)

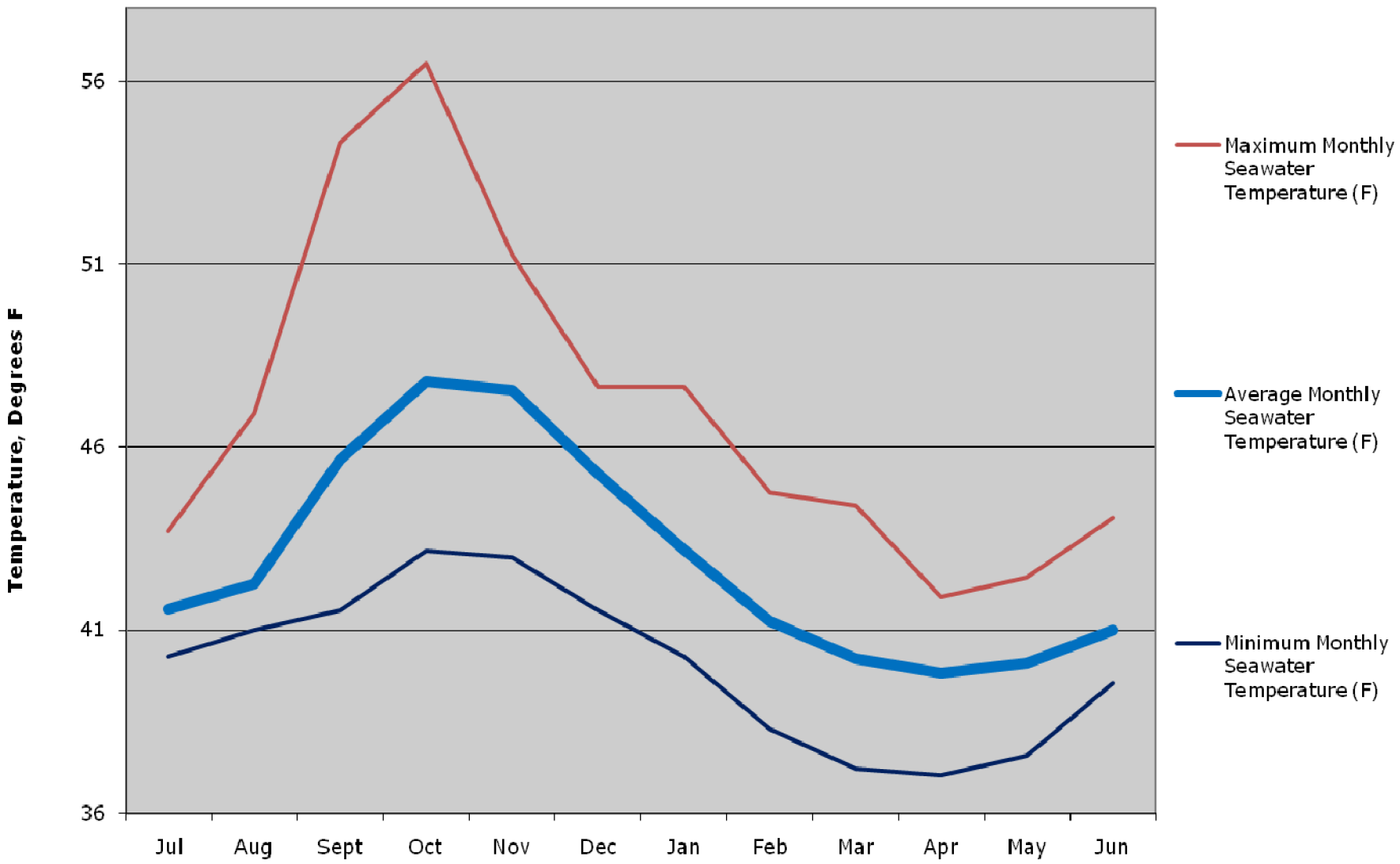
- The heat pump will pre-heat supply air for the building ventilation system.
- The GSHP test system also includes a solar thermal hybrid component that will help thermally recharge the GSHP ground loop field.
- Water-to-air
- Horizontal loop

Weller Elementary School Fairbanks

- Seawater heat pump system that will “lift” latent heat from raw seawater at temperatures ranging from 35ºF to 55ºF, transfer into building heat at a temperature of 120ºF.
- Space Heating
- Open-loop
- 90 Ton, 1080 MBH
- Commissioning in June

Alaska SeaLife Center Seward

ASLC Raw Seawater Temperatures for 2003-2008



- This project is an unique application of GSHP, as there are no known reports of a GSHP system being used to heat a large body of water such as pool
- Pool heating, space heating
- 1 water-to-water, 7 water-to-air
- Vertical loop, 164 wells

Dimond Park Aquatic Center Juneau

- 108 vertical wells
- Space heating/cooling, sidewalk ice melt
- 28 water-to-air, 3 water-to-water
- Expected maintenance costs are higher than the costs for the former heating oil system, due to the need for extra maintenance personnel
- Expected to save about $80,000 per year in operating costs, while avoiding the cost increases expected for heating oil prices

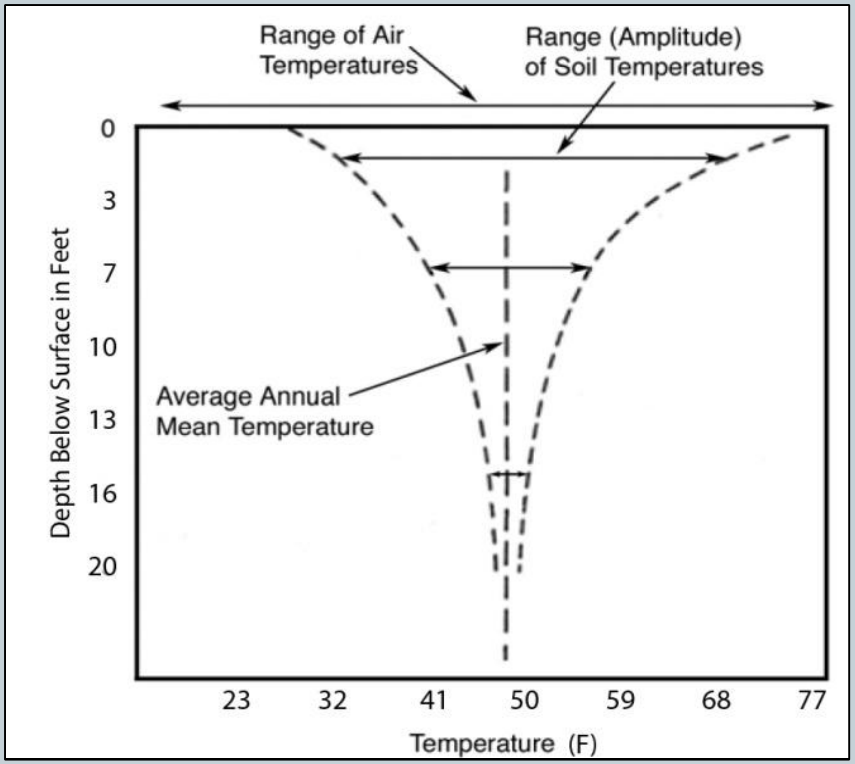
Juneau International Airport Terminal

Cold Climate Considerations

Cold Climates Considerations

Moderate Climates -

- Warmer soil temperatures
- Both heat extraction and rejection
- Lesser periods of heat extraction

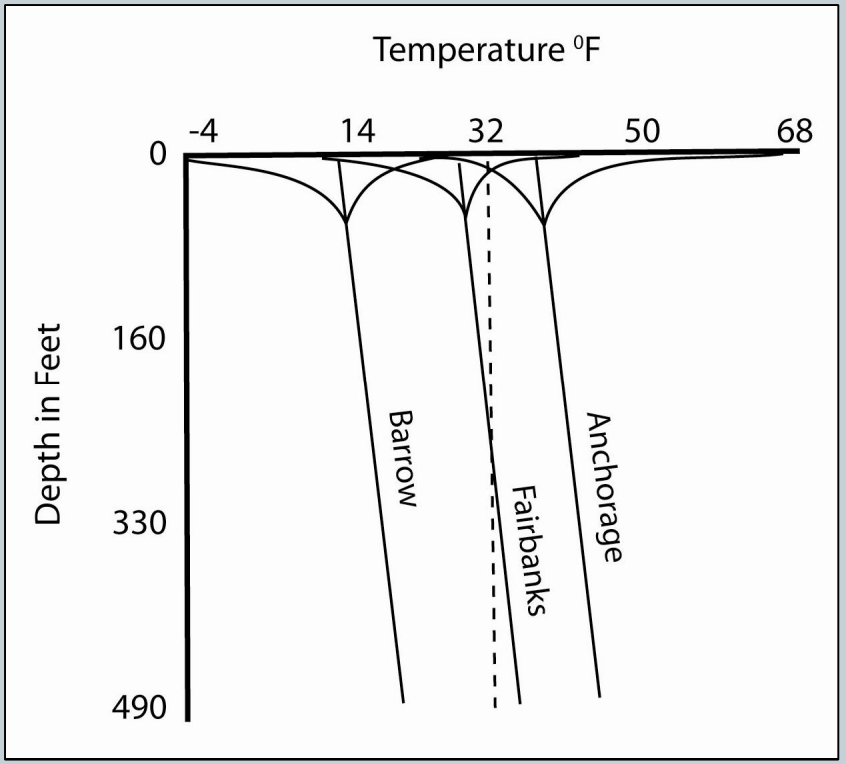


Graphic source: Hanova & Dowlatabadi, 2007

Cold Climates Considerations

Cold Climates -

- Lower average ground temperatures
- Typically only heat extraction
- Long, sustained periods of heat extraction

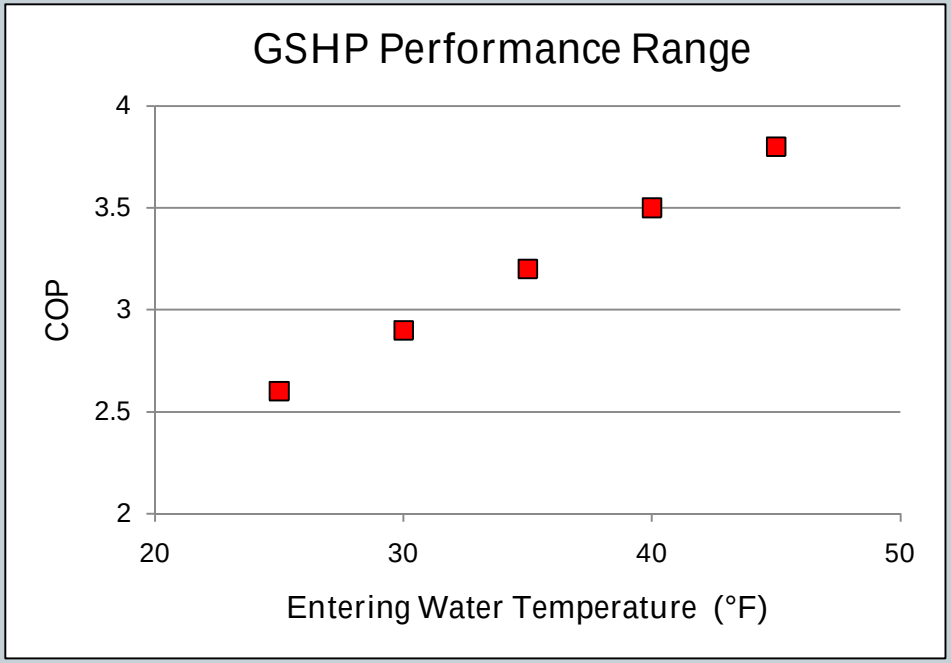


Graphic source: Rice, 1996

Cold Climates Considerations

Efficiency -

- Colder ground, lower efficiency
- GSHP operational limits
- Manufacturer's specs can estimate COP roughly
- Literature review found COPs from 2.0 – 3.9



Graphic source: Geological Survey of Canada

Cold Climates Considerations

Frozen Ground?

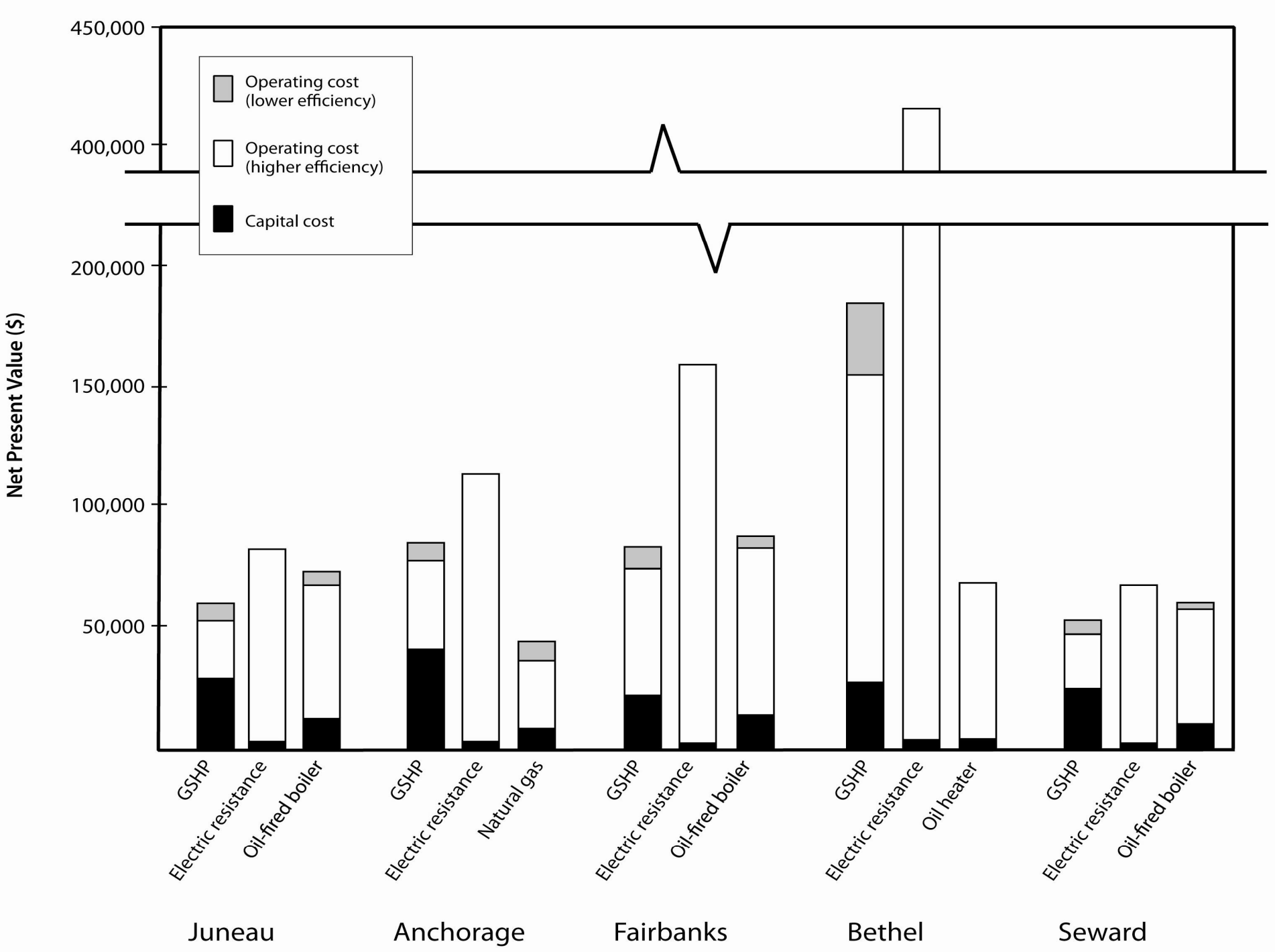
- Ground heaving, damage to utilities and structures?
- Evidence is scarce in the heat pump literature
- Cheaper than heating oil or natural gas?

Graphic source: Geological Survey of Canada

Preliminary Economic Assessment for Alaska

Design of Assessment

- 5 population centers:
  - Juneau, Anchorage, Fairbanks, Bethel, Seward
- Assumed new construction
- Average sized home
- Average annual heating per square foot
- Compared GSHP to typical home heating systems
  - Oil-fired boiler
  - Electric resistance
  - Natural gas (Anchorage)
  - Toyo stove (Bethel)


Net Present Value ($)
450,000
400,000
200,000
150,000
100,000
50,000
Operating cost (lower efficiency)
Operating cost (higher efficiency)
Capital cost
GSHP
Electric resistance
Oil-fired boiler
GSHP
Electric resistance
Natural gas
GSHP
Electric resistance
Oil-fired boiler
GSHP
Electric resistance
Oil heater
GSHP
Electric resistance
Oil-fired boiler
Juneau
Anchorage
Fairbanks
Bethel
Seward

Space heating energy use by population center

Community	Average home size	Annual average Btu/sq. ft.	Heating degree days
Juneau	1,730	75,818	8,897
Anchorage	2,074	87,894	10,570
Fairbanks	1,882	90,013	13,940
Bethel	1,554	91,486	12,769
Seward	1,730	75,818	9,007

Juneau

	GSHP	Electric resistance	Oil-fired boiler
Capital cost ($)	29,300	3,300	13,000
Annual energy cost ($)	1,400-1,700	4,300	3,300-3,700
Maintenance ($)	120	0	181
NPV ($)	56,300-61,500	82,500	71,300-75,900

Anchorage

	GSHP	Electric resistance	Natural gas furnace
Capital cost ($)	42,000	4,100	8,500
Annual energy cost ($)	2,000-2,400	5,900	1,500-1,800
Maintenance ($)	120	0	130
NPV ($)	79,300-86,500	114,100	49,900-59,500

Conclusions and Recommendations

"Technically and financially feasible cold climate GSHPs have been widely reported"

- A number of studies indicate that ground-source heat pumps (GSHPs) have been successful in cold climates.
- The range of COPs expected for professionally installed systems in Alaska is approximately 2.0 to 3.5 across a broad suite of locations, installers, heat sources, and heat pump manufacturers.
- A Canadian study surveyed GSHP users and found that 95% would recommend systems to theirs (Hanova & Dowlatabadi, Strategic GHG reduction through the use of ground source heat pump technology, 2007).

"Design is paramount for meeting performance expectations"

- A common error in colder climates is to make the ground loop small and the heat pump large, which results in increased electrical use and decreased efficiency (Dr. John Straube, personal communication, November 11, 2010).

- A Canadian desktop study confirms that the most common homeowner issues occur with poorly designed systems that result in thermal imbalance, where the soil cannot thermally recover, and low output temperature (Cottrell, 2009).

- An appropriate design for a given location will result in a higher COP that is more sustainable over time.

"GSHP systems, given regional considerations, are economically viable heating systems"

- GSHPs are most viable in regions with an abundance of cheap electricity (AEA, 2009).
- Despite higher capital cost, the net present value of using a GSHP is lower for Fairbanks, Seward, and Juneau when compared with other heating systems.
- Previous studies have asserted that high installation costs and potentially high operating costs make GSHPs inappropriate for rural Alaska (AEA, 2009).

"The lack of long-term studies on cold climate GSHPs make predicting their long-term performance difficult"

- Studies note that longer monitoring projects are needed to determine under what circumstances a GSHP will cause thermal degradation and whether the COP can be maintained for several years (Mueller & Zarling, 1996; Nielson & Zarling, 1983).
- The U.S. Department of Defense recommends studying the long-term performance of heat pumps to facilitate growth of the GSHP industry
- A few homeowners interviewed for this report have residential systems that have been in operation for more than ten years, with no noticeable decline in performance.

"Hybrid technology may improve the performance of cold climate GSHPs"

- Research suggests that hybrid systems are best for climates that are strongly heating- or cooling-dominated (Yang, Zhou, Xu, & Zhang, 2010) and that hybridization is sometimes necessary for cost-effectiveness (DoD, 2007).
- Most hybrid heating systems consist of a typical GSHP system that is augmented with a solar thermal system, used for supplementing the heat obtained from the ground loop in winter and for recharging the ground during summer.
- While hybrid GSHPs may perform better than non-hybrid GSHP in heating-dominated climates, they are not necessarily significantly more economical.

"Thermal imbalances in the soil can be created by GSHPs in cold climates"

- A ground loop must extract heat from the ground in order to heat a building. Whether ground temperatures can recover in the summer will depend on the region's climate, soil conditions at the site of the ground loop, and the sizing of the ground loop. In locations with low ground temperatures and a high annual heating demand, thermal imbalances are large concern.

Research Recommendations

- Focused Economic Analysis of GSHPs in Retrofit Construction
- Increasing Certainty for Cost Estimation
- Role of GSHPs in State Renewable Energy Targets
- Implications of GSHP Deployment in Southeast Alaska
- Analysis of Air-Source Heat Pumps for Moderate Cold Climates
- Long-Term Cold Climate Efficiency and Thermal Degradation
- Investigation on the Necessity of GSHP Hybridization

Questions?

- Thank you to the Denali Commission for supporting this study

- Project Partners include:
  - ACEP
  - CCHRC
  - AEA
  - NREL

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